



# **STRESS FREE TEMPERATURE TESTING AND CALCULATIONS ON OUT-OF-AUTOClave COMPOSITES**

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**Sarah B. Cox, LaNetra C. Tate, Susan E. Danley, Jeffrey W. Sampson, Brian J. Taylor/Kennedy Space Center  
Sandi G. Miller, James K. Sutter/Glenn Research Center**

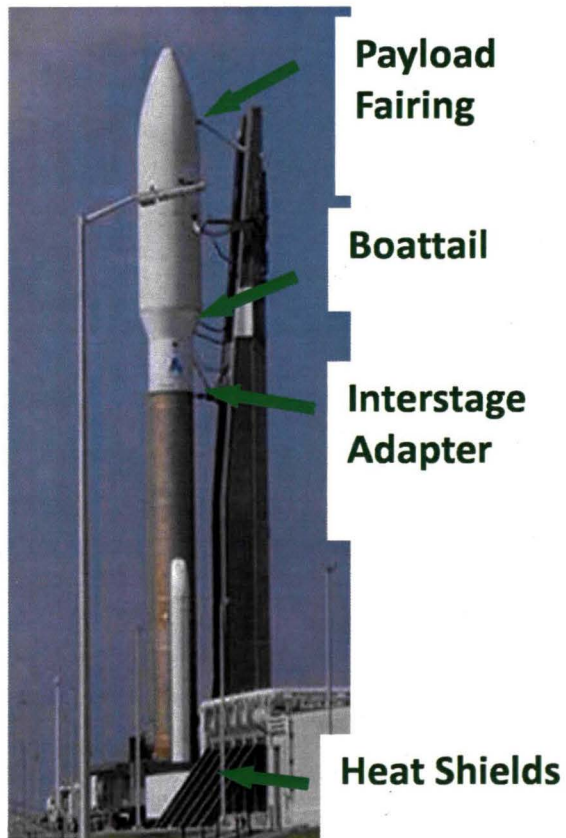
# Agenda/Outline

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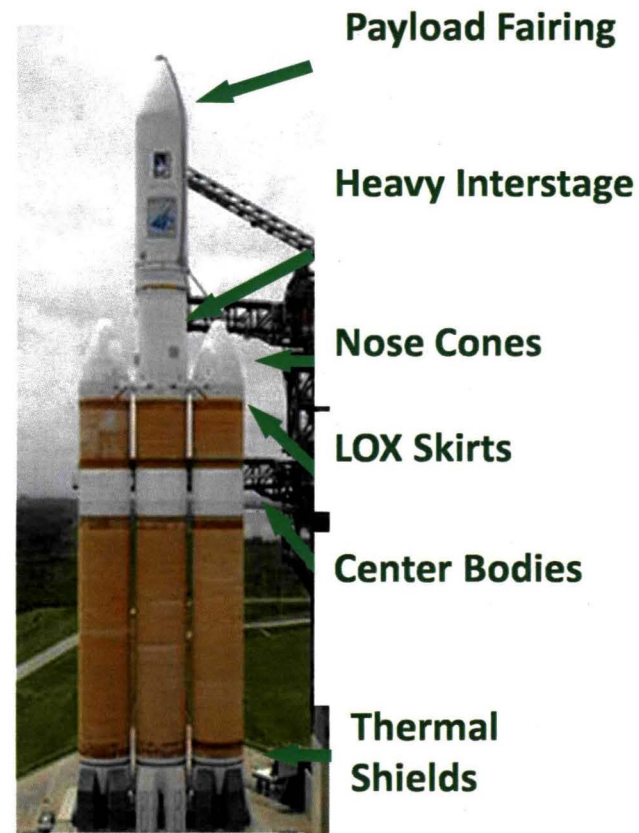


- Background on Composites for Exploration
- Test Panel Fabrication
- Stress Free Temperature Testing
- Results and Analysis
- Conclusion
- Questions

# Aerospace Applications

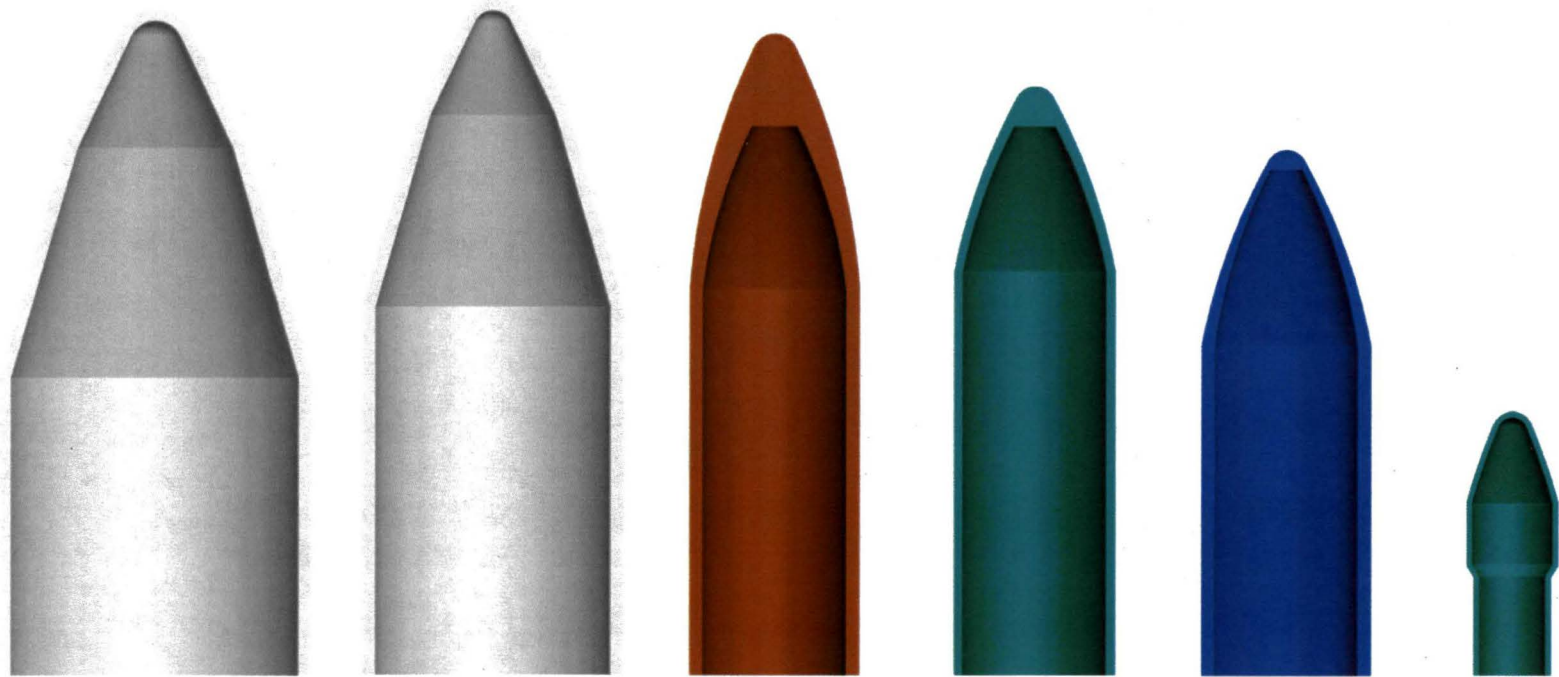


Atlas V



Delta IV

# Fairing Size Comparison



<u>Vehicle</u>	<u>Ares V</u>	<u>Ares V</u>	<u>Atlas V</u>	<u>Delta IV</u>	<u>Ariane</u>	<u>Delta II</u>
<b>Dia</b>	10 m	8.4 m	5.4 m	5.1 m	5.4 m	3 m
<b>Area</b>	~561 m <sup>2</sup>	~493 m <sup>2</sup>	~311 m <sup>2</sup>	~277 m <sup>2</sup>	~254 m <sup>2</sup>	~63 m <sup>2</sup>

# Composites for Exploration

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- Advancement of composite systems for large primary structures, by developing a composite payload fairing for heavy lift vehicle
- Demonstrate 25-30 percent weight savings and 20-25 percent cost savings for composite compared to metallic payload fairing structures
- Material Requirements
  - Out of Autoclave cure required due to size of structure
  - Maximum cure temperature of 177°C due to tooling temperature restrictions
  - High operating temperature to reduce amount of thermal protection needed



# Materials



- Out of Autoclave IM7/Bismaleimide (BMI) Prepreg Unitapes
  - **Renegade:** RM3004 developed to be cured at 191 °C (vendor did not recommend cure below 185 °C)
  - **Stratton Composites:** AR4500 developed to be cured at 191 °C
  - **Tencate:** RS8-OOA developed to be cured at 177 °C

# Residual Stress in Composite Panels



Residual stress due to thermal mismatch  
between the matrix and the fiber

$$\sigma_A = \frac{1}{d_A} \left( \frac{(\alpha_B - \alpha_A)\Delta T}{\frac{1 - \nu_A}{d_A E_A} + \frac{1 - \nu_B}{d_B E_B}} \right)$$

$d$  = layer thickness

$\alpha$  = Coefficient of Thermal Expansion

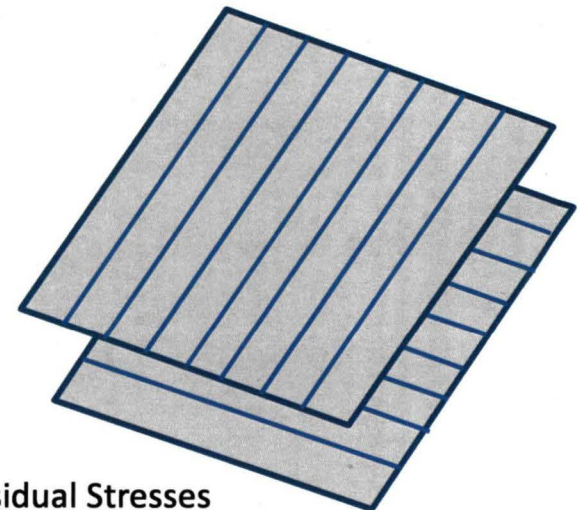
$\Delta T = T_{SF} - T$

$T_{SF}$  = Stress Free Temperature

$T$  = Current Temperature

$\nu$  = Poisson's Ratio

$E$  = Young's Modulus



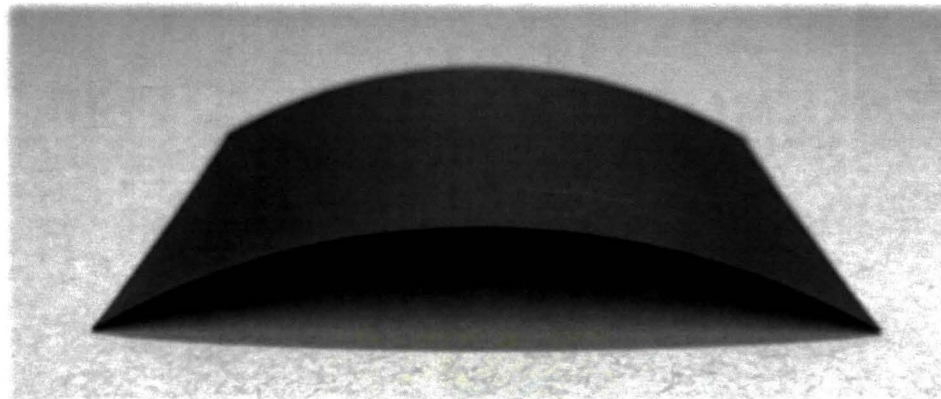
Ref: McGinnis, Arthur J.; Watkins Thomas R.; and Jagannadham K., "Residual Stresses in a Multilayer System of Coatings," JCPDS-International Centre for Diffraction Data, 1999. pp 443-454.

# Test Panel Configuration

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- Asymmetric Panels (2 ply [0,90])
  - Room Temperature, Dry (Desiccator for 24 hours)
  - Environmental Exposure (Humidity Chamber at 75% RH and 32°C for 7-10 days)
  - Each panel is 15.2 cm X 15.2 cm

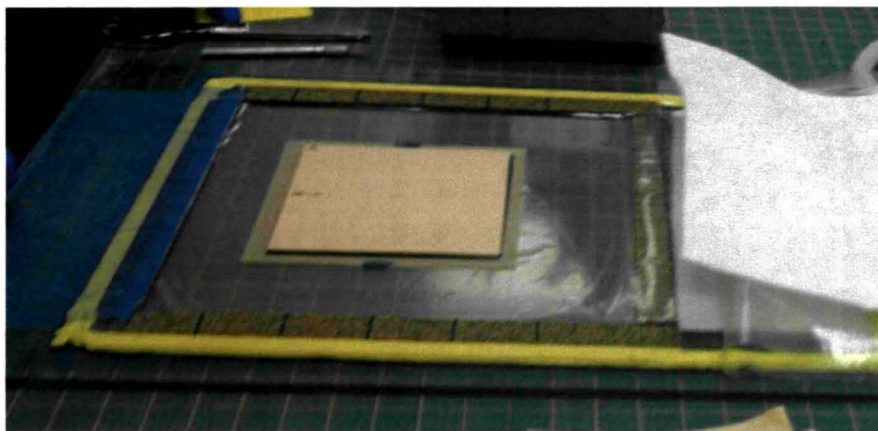




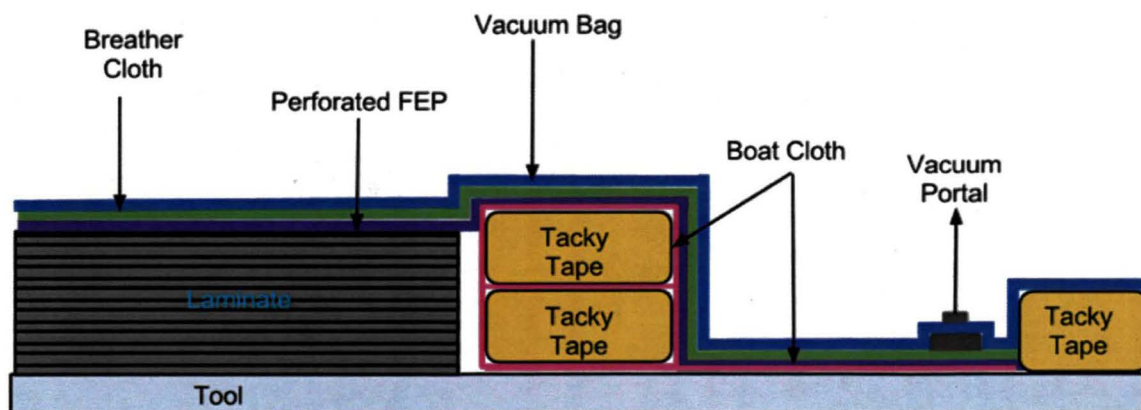
# IM7/BMI Panel Fabrication



## Hand Lay Up Method



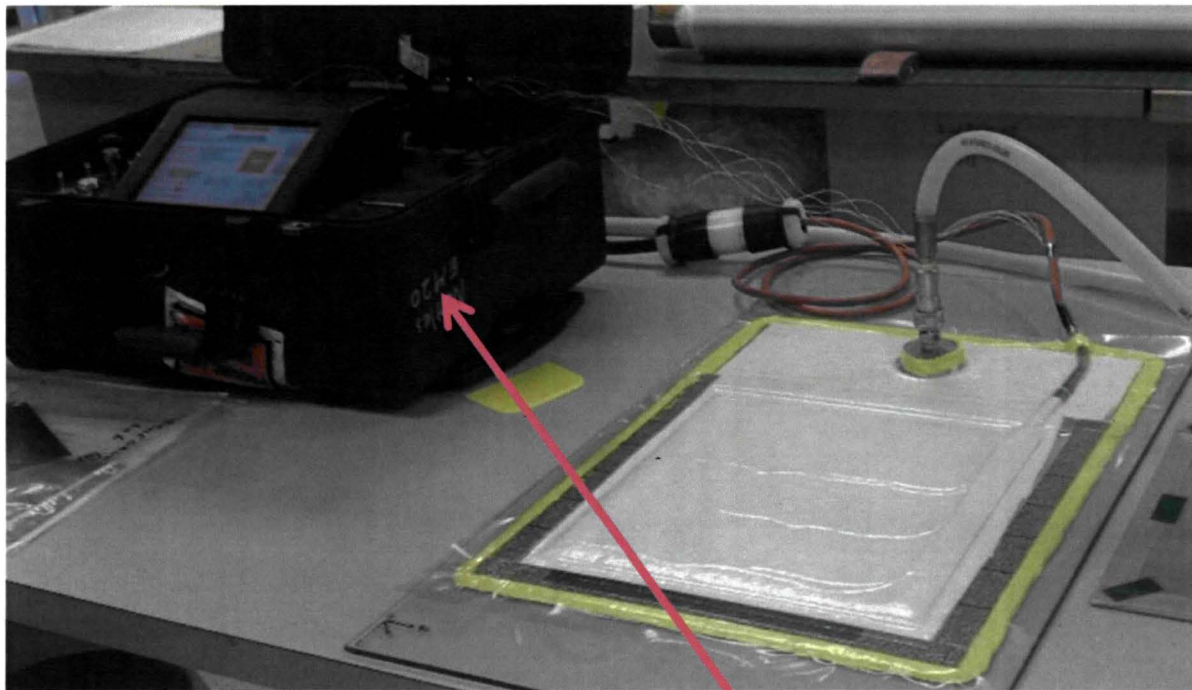
## Example of Bagging Schedule



# Heated Debulk

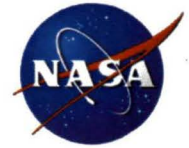


Heated debulk used to simulate the heat and pressure applied by the Automated Fiber Placement Tool

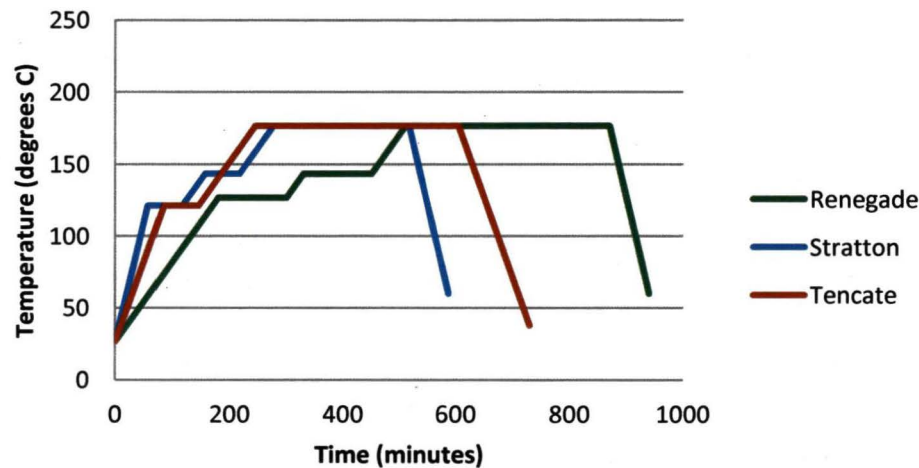


Heated Debulk Using a Hot Bonder

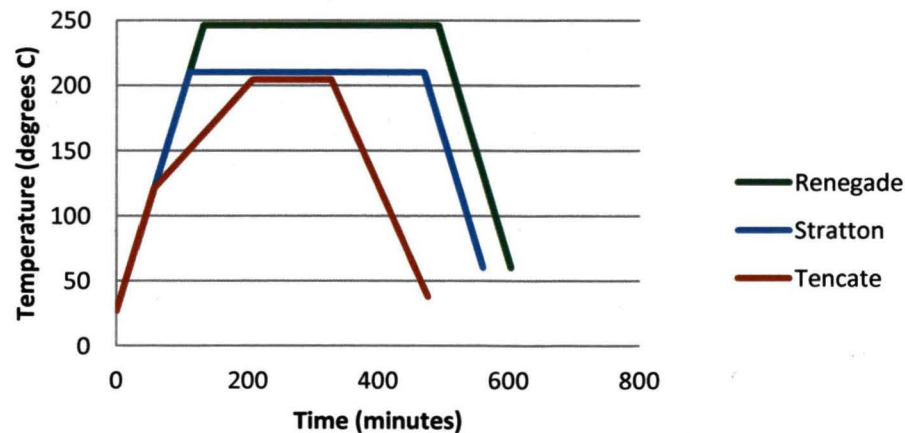
# BMI Panel Cure Cycles



## BMI Cure Cycle



## BMI Postcure Cycle



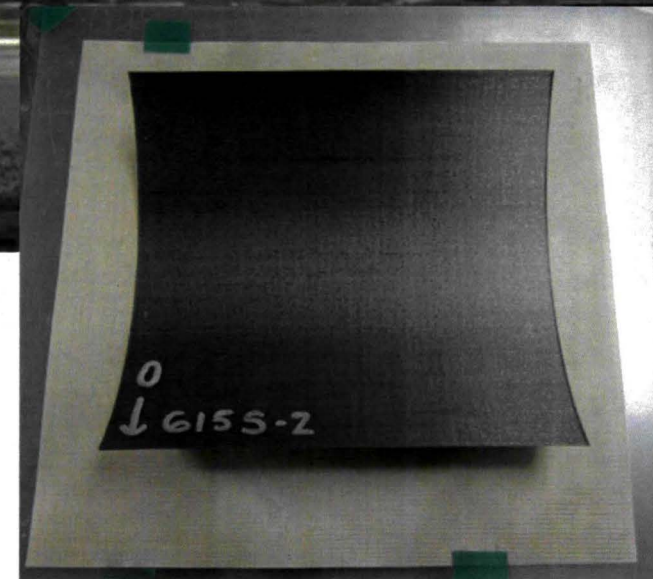
Oven Cure of Panel Under Vacuum



# BMI Free Standing Post Cure



Panels in the oven for a free standing post cure



Fully Cured Panel

# Test Panel Configuration



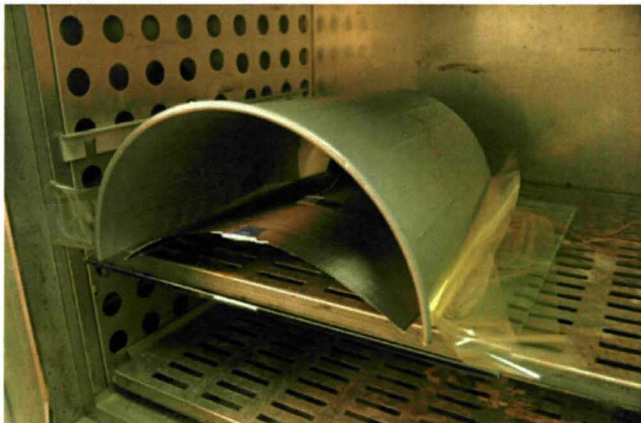
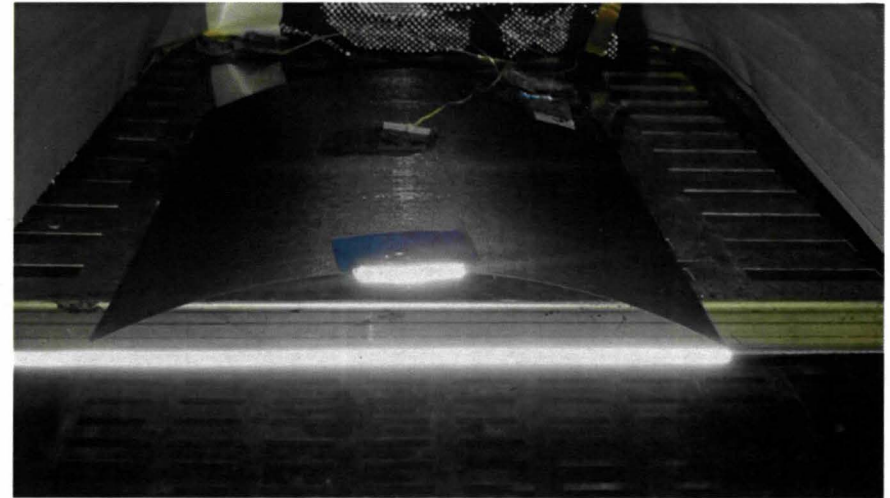
PANEL	MANUFACTURER	SET	HEATED DEBULK TEMP (DEG C)	CONDITION	% WEIGHT GAIN
615-R1	Renegade	1	40	Environmental	
615-R2	Renegade	1	40	Room Temp, Dry	
615-S1	Stratton	1	40	Environmental	0.651
615-S2	Stratton	1	40	Room Temp, Dry	
615-T1	Tencate	1	30	Environmental	0.445
615-T2	Tencate	1	30	Room Temp, Dry	
630-R1	Renegade	2	60	Environmental	0.894
630-R2	Renegade	2	60	Room Temp, Dry	
630-S1	Stratton	2	60	Environmental	
630-S2	Stratton	2	60	Room Temp, Dry	
630-T1	Tencate	2	60	Environmental	0.493
630-T2	Tencate	2	60	Room Temp, Dry	



# Stress Free Temperature Testing

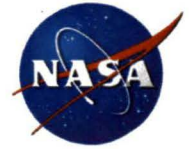


- Asymmetric panel flattens as it is heated
  - Thermocouples measured panel temperature
  - Reflective tape and a laser extensometer measured distance from the top of the curvature to the glass plate



# Video of Panel Flattening

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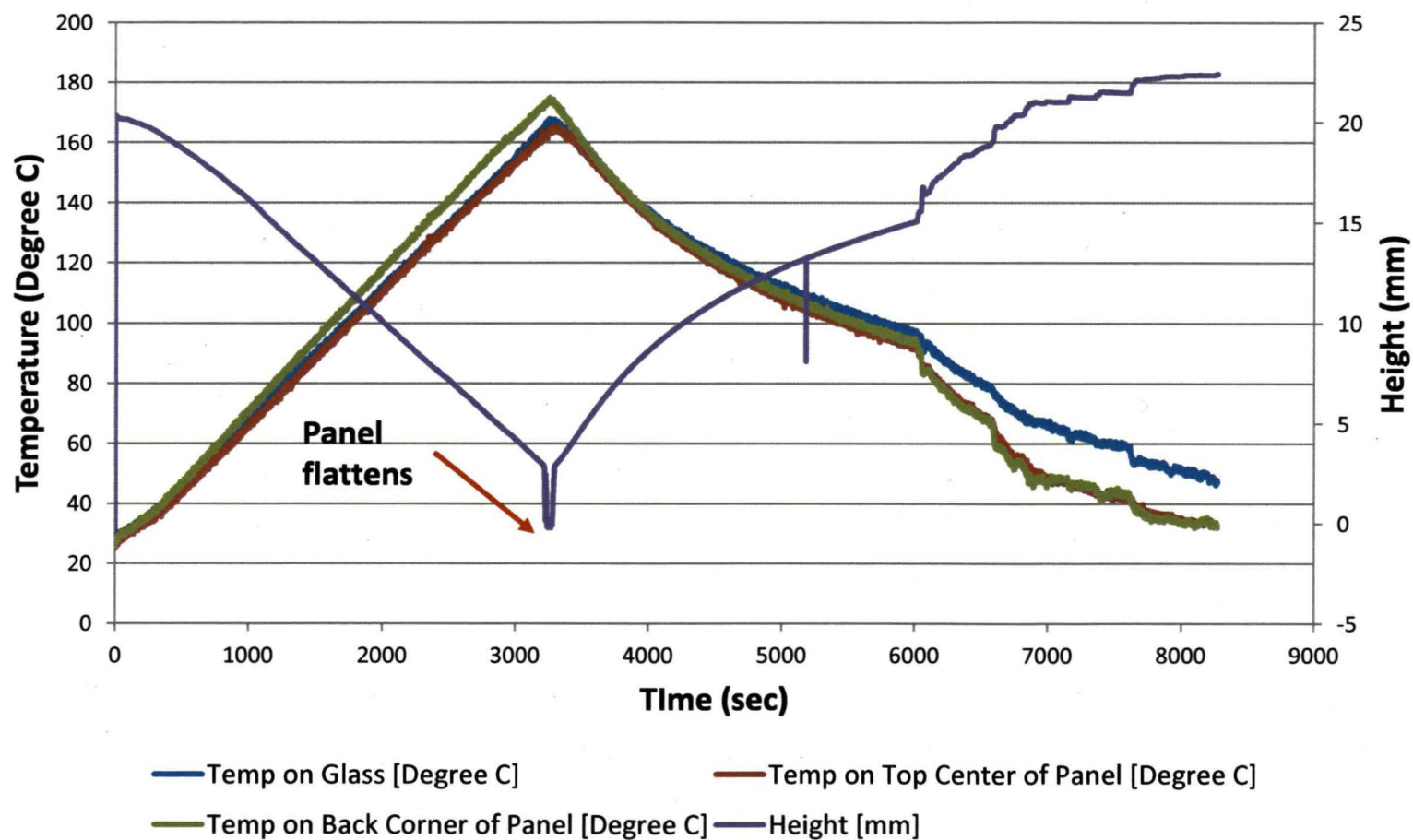


- Will insert video (630R2)



# Testing Profile

Panel 615-T2

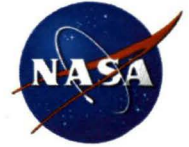


# Results

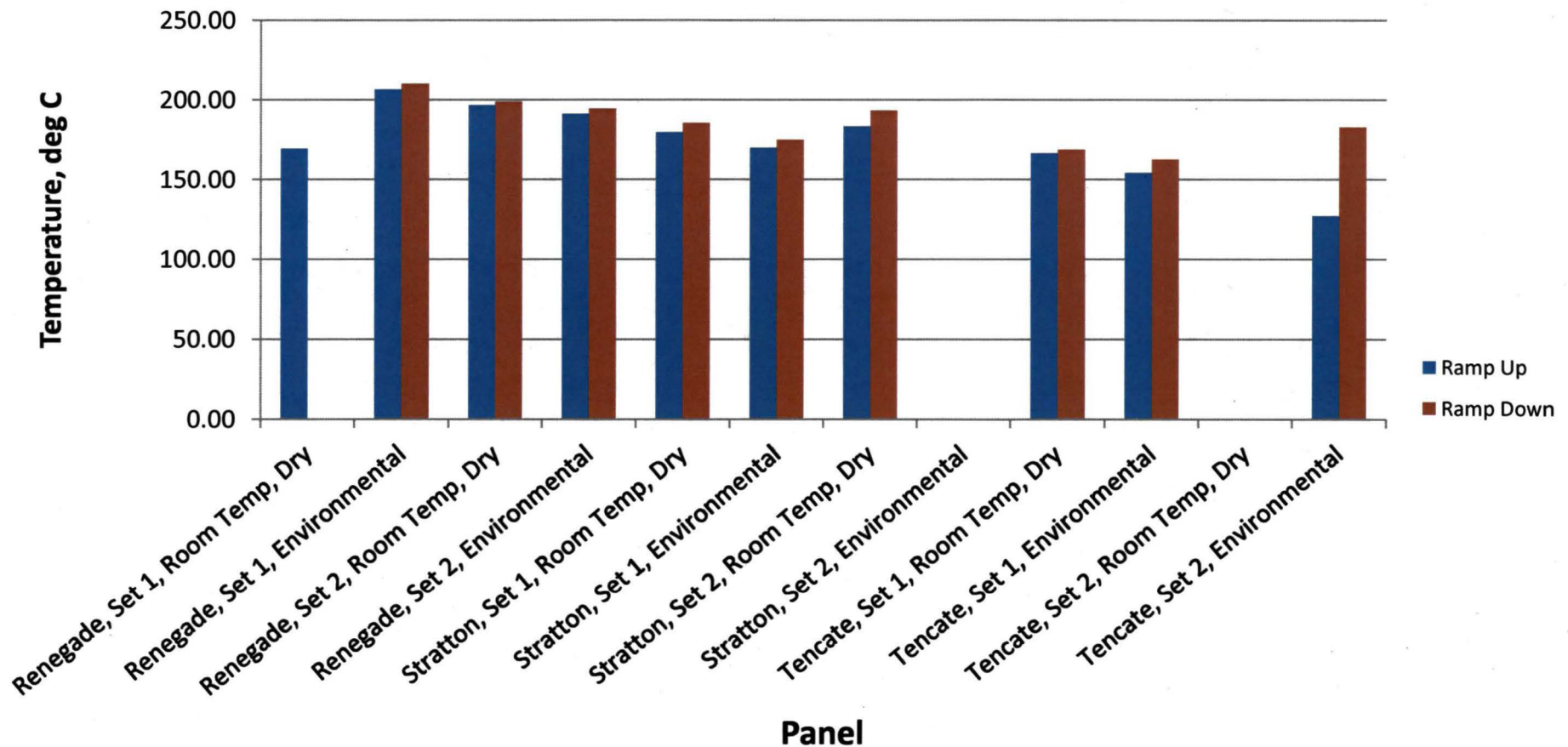


PANEL NUMBER	PANEL DESCRIPTION				AVG STRESS FREE TEMP ON PANEL (degree C)
615-R1	Renegade	Set 1	Environmental	Ramp Up	206.44
				Ramp Down	209.89
630-R1		Set 2	Environmental	Ramp Up	191.06
				Ramp Down	194.31
615-R2		Set 1	Room Temp, Dry	Ramp Up	169.33
				Ramp Down	196.50
630-R2		Set 2	Room Temp, Dry	Ramp Up	196.50
				Ramp Down	198.72
615-S1	Stratton	Set 1	Environmental	Ramp Up	169.72
				Ramp Down	174.72
615-S2		Set 1	Room Temp, Dry	Ramp Up	179.58
				Ramp Down	185.25
630-S2		Set 2	Room Temp, Dry	Ramp Up	183.25
				Ramp Down	193.06
615-T1	Tencate	Set 1	Environmental	Ramp Up	154.17
				Ramp Down	162.44
630-T1		Set 2	Environmental	Ramp Up	127.03
				Ramp Down	182.75
615-T2		Set 1	Room Temp, Dry	Ramp Up	166.47
				Ramp Down	168.61

# Ramp Up vs. Ramp Down

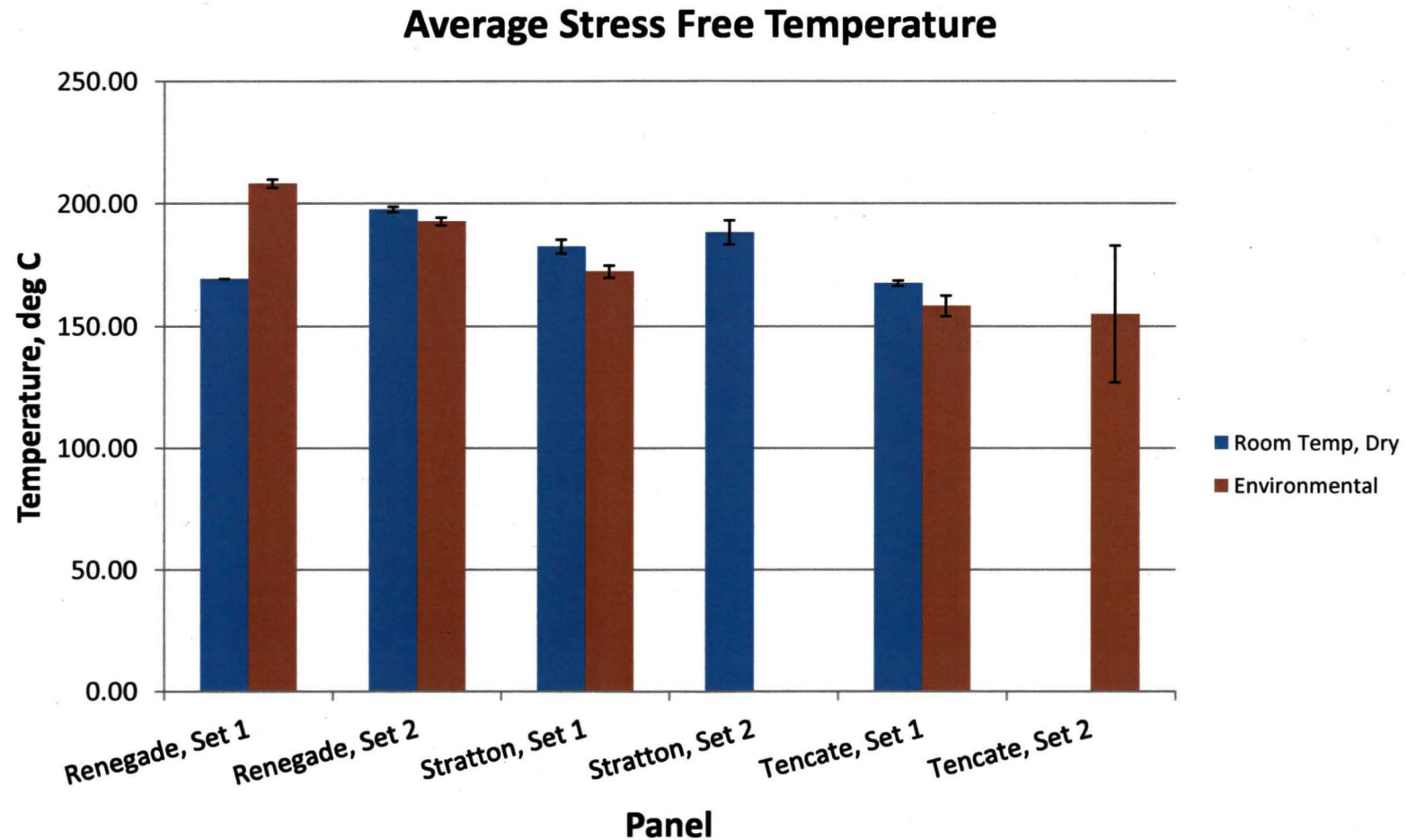


Average Stress Free Temperature





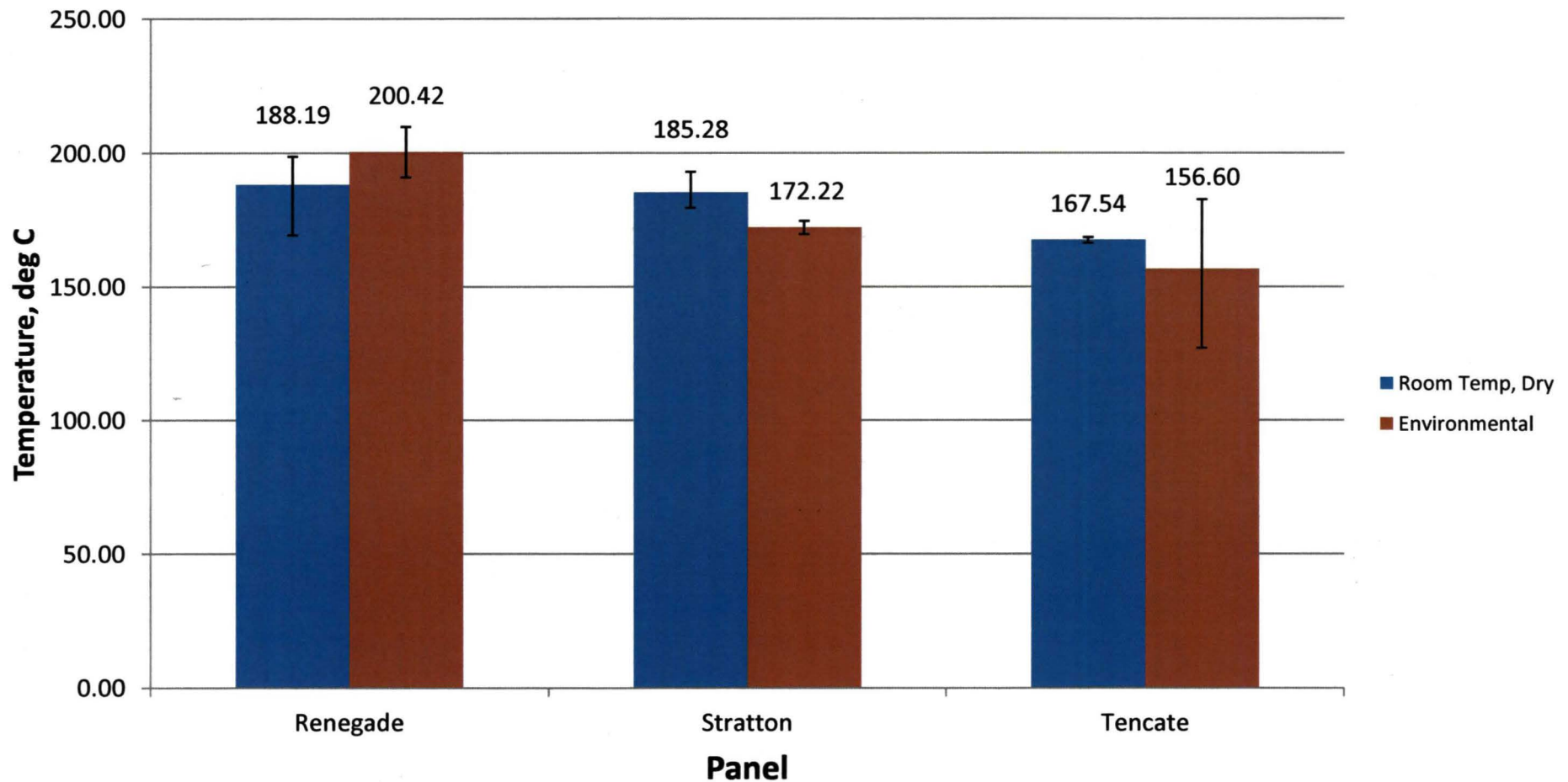
# Room Temperature, Dry vs. Environmental – Each Panel



# Room Temperature, Dry vs. Environmental - Averaged



**Average Stress Free Temperature**



# Summary

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- Stress free temperatures were determined by heating asymmetric panels
- This can be used to determine the residual stress
- Environmental exposure does have an effect on the stress free temperature
- There is a correlation between the recommended cure temperature and the stress free temperature

# Composites for Exploration



CoEx Project Manager

Dr. Mark J. Shuart, Langley Research Center

Materials and Manufacturing Co- Leads

Larry Pelham, Marshall Space Flight Center

Dr. Jim Sutter, Glenn Research Center

Materials Subtask Lead

Dr. Sandi Miller, Glenn Research Center

KSC CoEx POC

Anne Caraccio, Kennedy Space Center

Sarah Cox, Kennedy Space Center

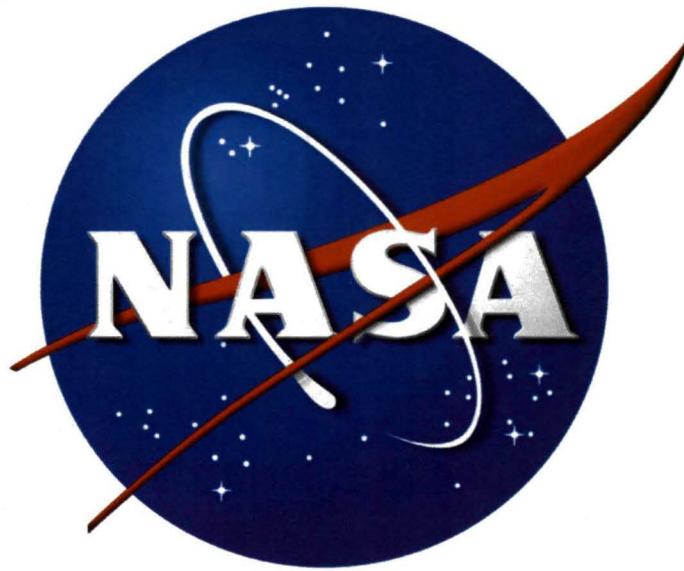
Supporting Kennedy Space Center Team Members

Dr. LaNetra Tate\*, Susan Danley,

Jeffrey Sampson, Brian Taylor

\* Former KSC CoEx POC and Repair Subtask Lead, currently Detailed to NASA HQ/NIST

# QUESTIONS?





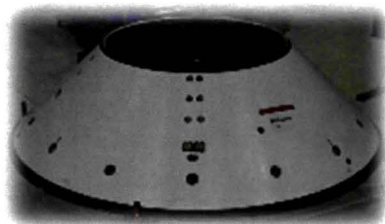
**BACK UP**

# Sea Launch Payload Accommodations



## Composite Faring

4.15 m dia  
10.5 m long

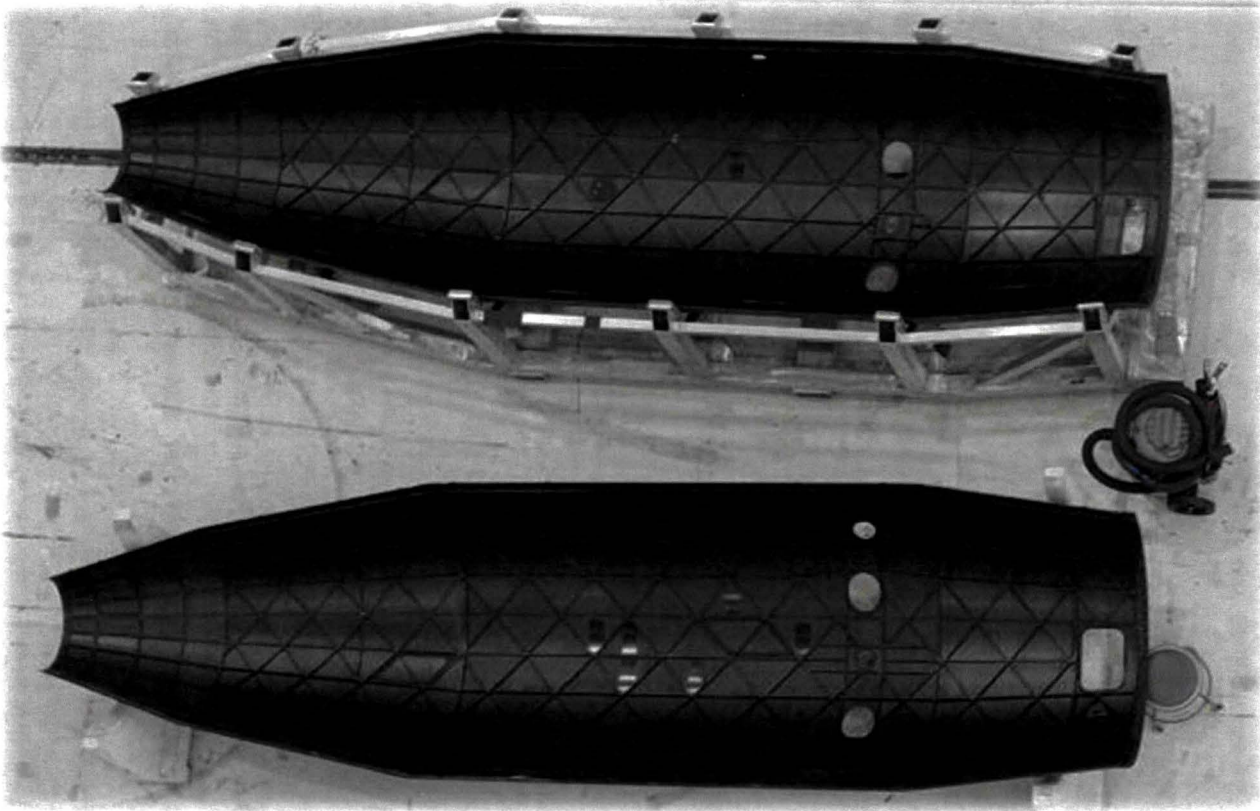


## Composite Payload Structure



# Minotaur Payload Fairing

AFRL development with Orbital Sciences

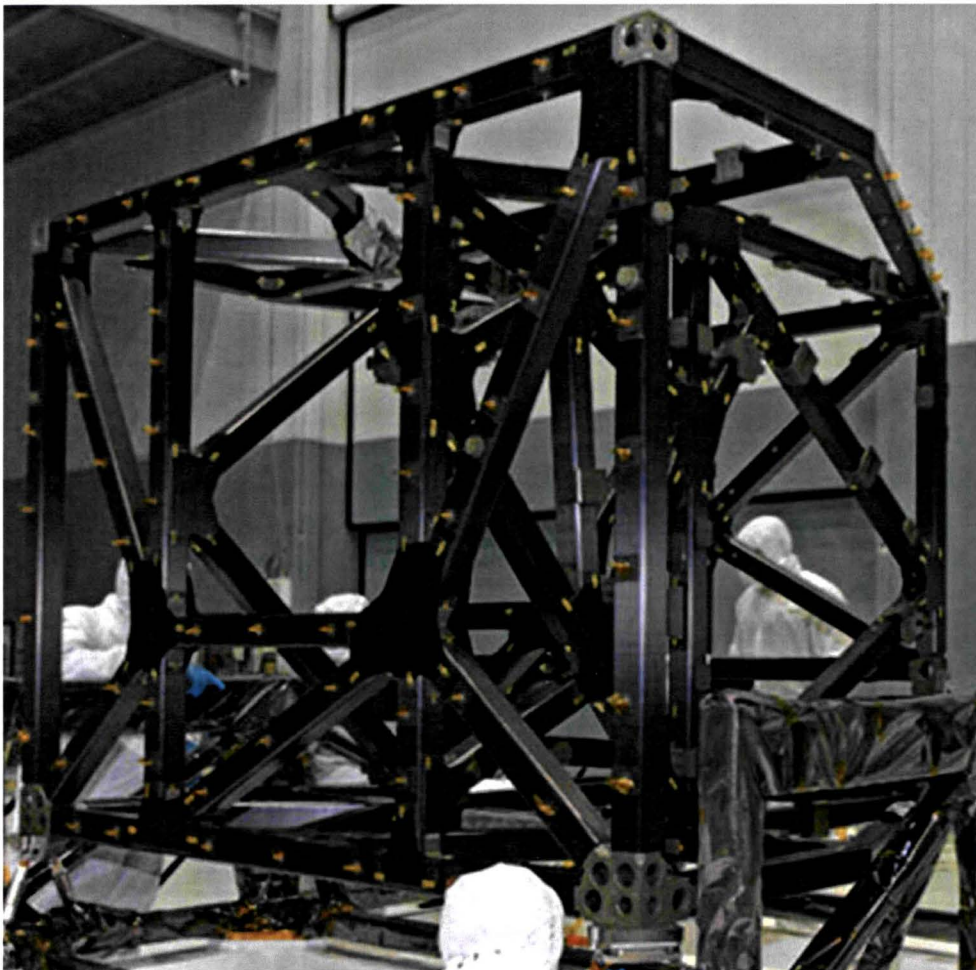


**1.55 m diameter**  
**Launched in 2006**



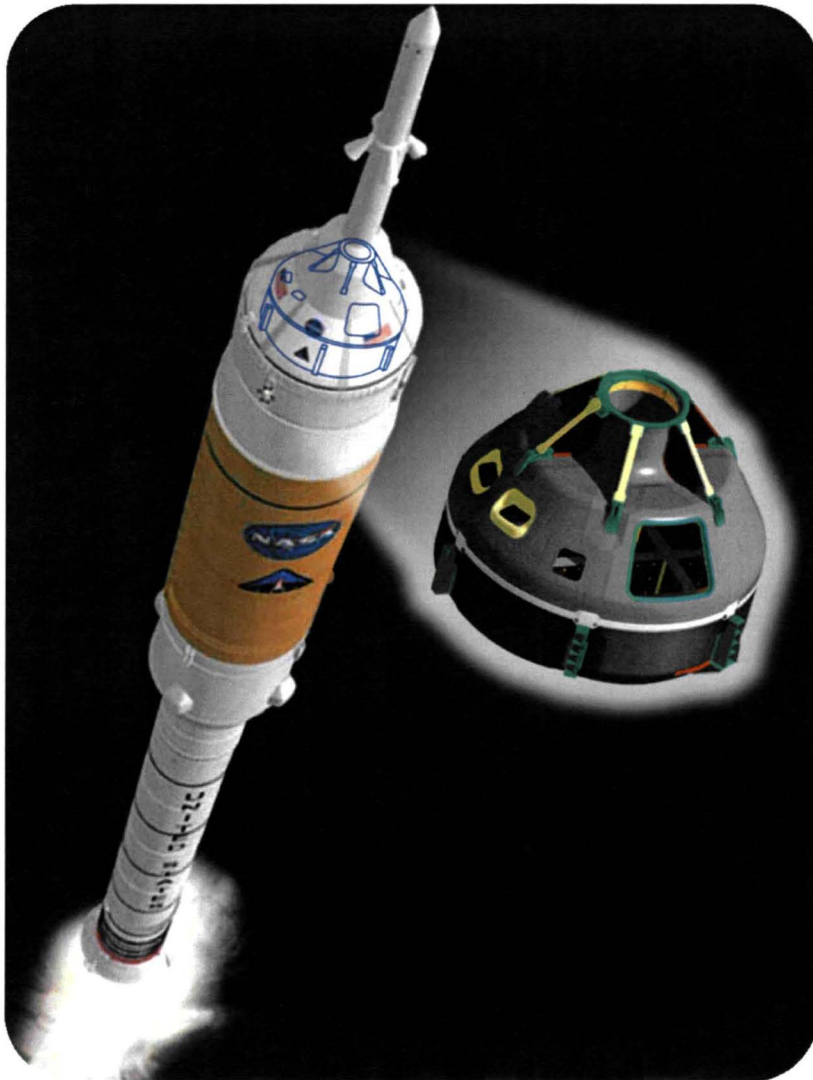


# Integrated Science Instrument Module



- Protoflight hardware developed for James Webb Space Telescope and to be flown on an Ariane V
- Technology highlights
  - Cryogenic joints
  - Hybrid laminates for near-zero coefficient of thermal expansion operating at cryogenic temperatures
- Benefit: reduced thermal distortion

# NASA Composite Crew Module



- **Combined Sandwich and Solid Laminate Construction**
- **Solid Laminate**
  - Tunnel
  - Main Parachute Attach
- **Sandwich Panels**
  - Ceiling
  - Conic section
  - 2.5-cm-thick aluminum core
- **IML and OML Facesheets Symmetric**



# Composites for Exploration Project



## Vehicle

## Heavy Lift

## Atlas V

## Delta IV

**Dia**

**10 m**

**5.4 m**

**5.1 m**

**Area**

**~561 m<sup>2</sup>**

**~311 m<sup>2</sup>**

**~277 m<sup>2</sup>**

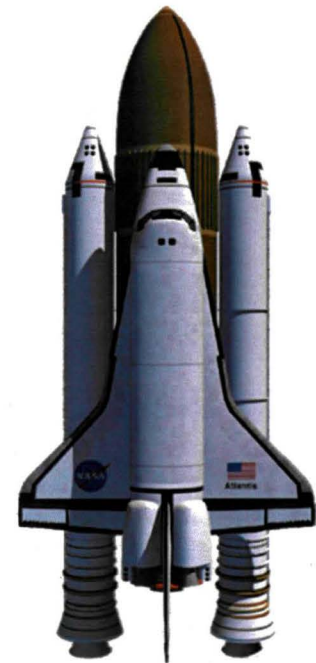
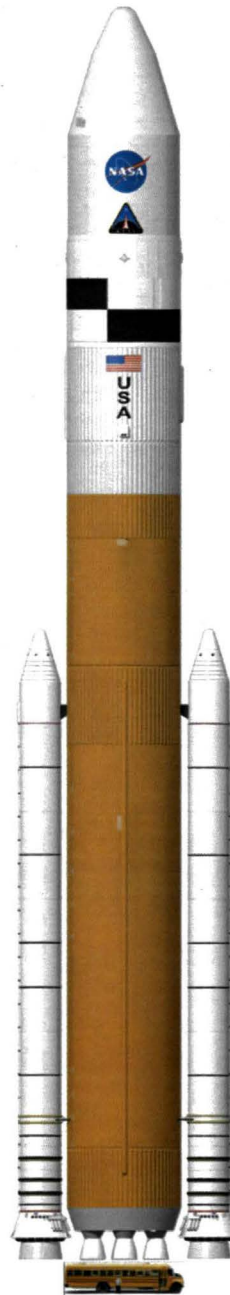
CoEx Thrust	SOA
Panels for 10-m-dia. barrels	No composites experience at this scale
Automated manufacturing	Limited to 7-m-dia. barrels
OoA* technologies	Maturing for aerospace quality
Design database	Not demonstrated for 10-m-dia. barrels

Demonstrate 25-30 percent weight savings and 20-25 percent cost savings for composite compared to metallic payload fairing structures

**\*out of autoclave**

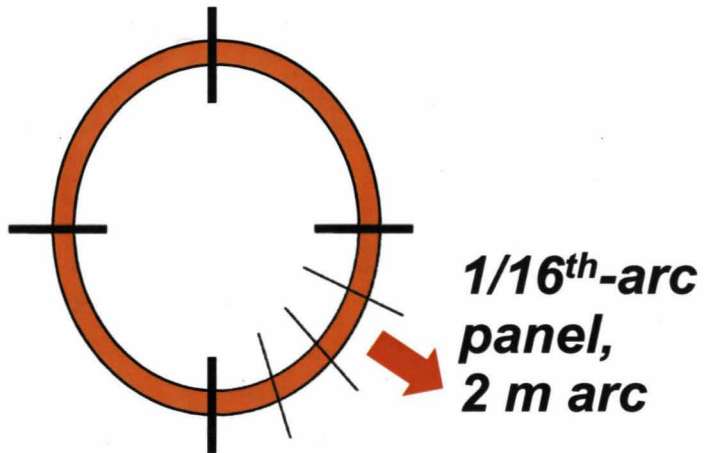
# Size Comparisons

***Composite structures for heavy lift launch vehicles will be the largest composite aerospace structures ever built!***



# Manufacturing Summary

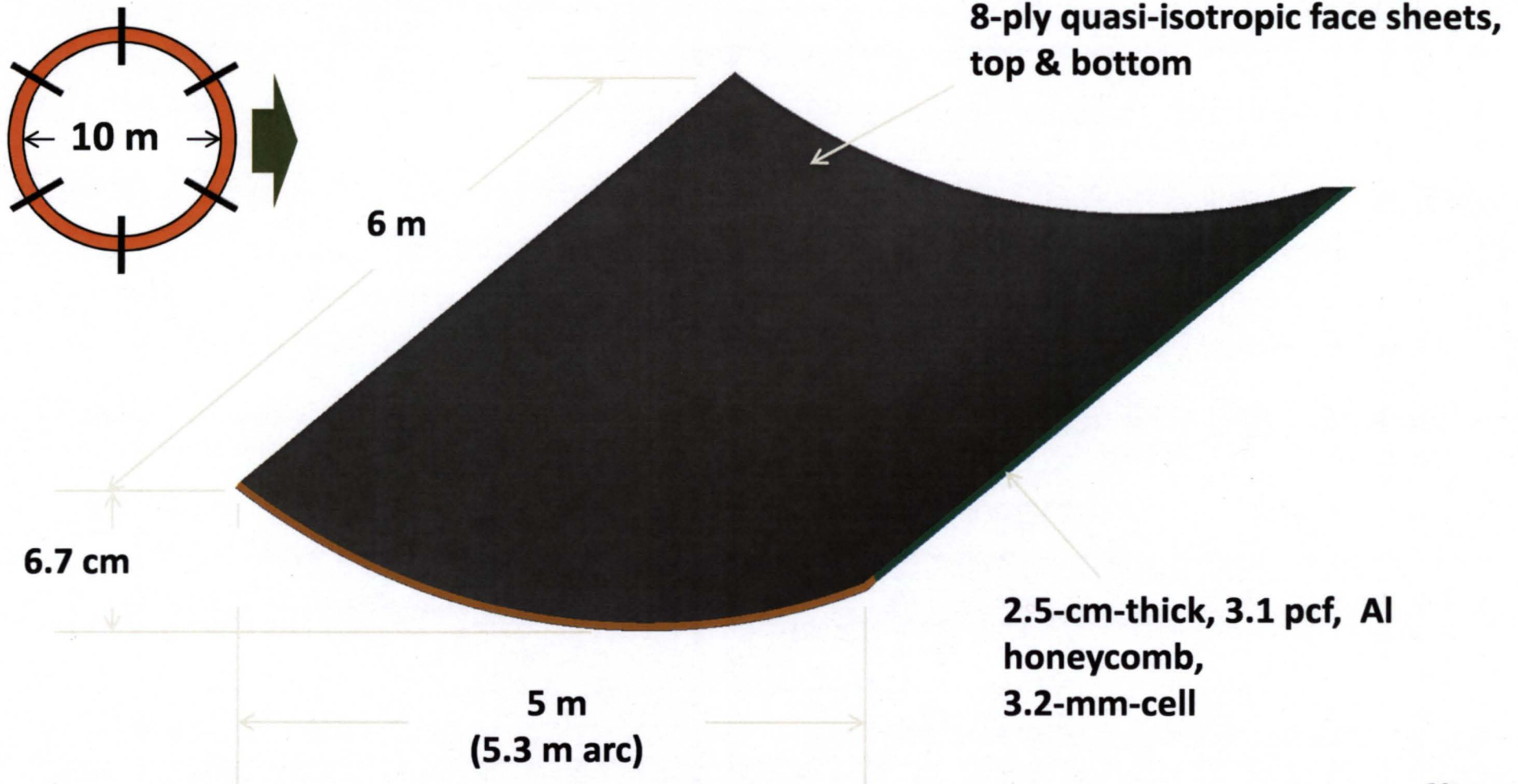
- Manufacturing plans are being guided by modeling of fabrication processes
- NASA fabrication of 1/16<sup>th</sup>-arc panels is first step to fabricating larger structures



**1/16<sup>th</sup>-Arc Panel Tool Fabrication**

# Preliminary 1/6<sup>th</sup>-Arc Panel

***\*\*not to scale\*\****





# 1/6<sup>th</sup> – Arc Panel Fabrication

